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**AN ANALYSIS OF ROOF WASHDOWN VERSUS APPLIED
SHIELDING AS A FALLOUT COUNTERMEASURE**

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Menlo Park, California

December 1966

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December 1966

AN ANALYSIS OF ROOF WASHDOWN VERSUS APPLIED SHIELDING AS A FALLOUT COUNTERMEASURE

By: HONG LEE

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ABSTRACT

This study provides guidance on the basic applicability and relative worth of roof washdown as a fallout radiation countermeasure. The basic purpose of roof washdown is to reduce the radiation dose to occupants of a building by preventing or reducing the accumulation of fallout on the roof. However, the roof washdown system does not affect the penetration of the roof by radiation from other sources.

It was found that under some circumstances a roof washdown system is a useful means for increasing the protection of building interiors and that, in general, the cost of a washdown system for large roof area structures with smooth sloped roofs will be less than the cost of providing an equivalent amount of shielding. However, solid shielding provides 100 percent reliability whereas roof washdown systems may not be as reliable.

CONTENTS

INTRODUCTION	1
Background	1
Objectives	2
WASHDOWN EFFECTIVENESS	3
Dose Rates and Dose Considerations	3
Dose Rate from Roof Residual Fallout	4
Transit Dose Rate	4
Dose Rate from Adjacent Surfaces	4
Accumulated Doses in Terms of Contributing Components	8
COMPARATIVE COSTS	24
OTHER CONSIDERATIONS	28
CONCLUSIONS	29
REFERENCES	30

ILLUSTRATIONS

1	Example Fallout Deposition Rate	5
2	Fallout [†] Accumulation	6
3	Relative Dose Rates from Accumulated Fallout	7
4	One Week Dose Components for 10 Foot Tall Structures with No Shielding Assumed	9
5	One Week Dose Components for 20 Foot Tall Structures with No Shielding Assumed	10
6	Roof Contribution Percentage (20 Foot Tall, 1,000 Sq Ft Structure)	12
7	Structure Geometry-Dose Reduction Factors	14
8	Roof Attenuation Factors	15
9	Wall Attenuation Factors	16
10	Calculated Protection Factors for 10 Foot Tall Structures .	17
11	Calculated Protection Factors for 20 Foot Tall Structures .	18
12	Equivalent Roof Thickness of Washdown System-10 Foot High Roof	19
13	Equivalent Roof Thickness of Washdown System-20 Foot High Roof	20
14	Required Roof Thickness to Obtain a PF of 40 for Structures with 150 PSF Walls	21
15	Washdown Water Flow Rates	23
16	Additional Cost of Open Truss Roof Support	25

TABLES

INTRODUCTION

Background

Water washdown was originally proposed as a method of preventing the buildup of seawater fallout on ships' weather surfaces. Performance tests with actual fallout demonstrated that washdown was feasible and capable of significantly reducing residual contamination levels.¹ The ship washdown system (an older name for it was "water curtain") consisted of an automatic sprinkling system, which could be activated upon warning, and could operate indefinitely, using seawater from the ship's continuously replenished supply. The constant streams of water functioned as both a barrier and decontaminant. The water formed a fluid film over the ship's surfaces to dissolve the depositing seawater fallout and prevented most of the dissolved radionuclides from coming in contact with the ship's weather surfaces or, if the seawater fallout did contact the surfaces, the water was intended to dissolve the residue and carry it over the side into the ocean. Since the washdown was initiated before or during fallout, two separate benefits were obtained:

1. A reduced exposure dose to ship personnel during the fallout period
2. A decontaminated ship after fallout cessation

It was a natural suggestion that an automatic washdown system might be applied, with similar benefits, to the roof of a building for the removal of solid fallout particles formed by land surface detonations. There are, however, a number of important differences between the ship and the shore applications. Buildings (1) do not possess mobility, (2) generally are not surrounded by an infinite supply of water, (3) are not equipped with large water-pumping capabilities, and (4) generally are not surrounded by an infinitely deep activity sink. Finally, the mechanism of removal of solid particles is quite different from the mechanism of removal of the soluble seawater fallout that is produced by detonations near the surface of the ocean. Although the effectiveness of a roof washdown system has not been tested with real fallout from land detonations or any other type of nuclear detonation, there are a few buildings in the country that are equipped with washdown systems.²

The present study is an attempt to provide guidance on the basic applicability and relative worth of roof washdown as a fallout radiation countermeasure. This type of study is not new.^{3,4} An unpublished USNRDL report by S. Salkin⁵ contained a similar study. The topic was also discussed in a short note by P. D. LaRiviere and H. Lee⁶ (also unpublished). This presentation is an extension of these studies.

Objectives

The objectives of this study are:

1. To determine the feasibility of incorporating a roof washdown system in some structures in lieu of adding shielding materials to the roof for the purpose of converting these structures to radiological shelters.
2. To compare the performance and characteristics of applied shielding with those of roof washdown.
3. To apply a cost analysis as a basis for the selection of options.

WASHDOWN EFFECTIVENESS

Dose Rates and Dose Considerations

The basic purpose of roof washdown is to reduce the radiation dose to occupants of a building by preventing or reducing the accumulation of fallout on the roof. However, the roof washdown system does not affect the penetration of the roof by radiation from other sources. Thus, in addition to the dose rate from the roof fallout deposit, two other dose rate contributors to the total dose rate received by building occupants through the roof must be considered, and also the different contributions must be considered over two time periods: (1) the time during fallout and (2) the time after fallout cessation.

1. Dose rate during fallout

- a. Roof deposit dose rate. The source of this radiation is the fallout particles that are actually deposited on the roof; its magnitude depends on the roof retention rate (with or without a washdown system) and the amount of fallout deposited to a given time.
- b. Transit dose rate. The source of this radiation is the air borne fallout particles in the air near the building at any time before fallout cessation. The magnitude of this radiation is not influenced by washdown.
- c. Adjacent surface dose rate. The source of this air-scattered radiation is the fallout that has been deposited (at a given time) on surrounding roofs or ground areas. The magnitude of this radiation is not influenced by washdown (unless the system is also used on these areas).

2. After fallout cessation

In this period, the fallout particles have all been deposited; hence the transit dose rate is zero. The components of the dose rate received through the roof are:

- a. Roof deposit dose rate. The source of this radiation is the fallout particles remaining on the roof. Its magnitude depends on the density of the remaining deposit, and time after deposit (variation due to weathering and decay).
- b. Adjacent surface dose rate. The source of this radiation is the fallout deposited on surrounding surfaces (other roofs and the ground).

If a washdown system removes a given fraction of the depositing fallout, independent of the time after start of fallout, the effectiveness of roof washdown can be approximated by calculations using the fraction remaining after fallout cessation.

Dose Rate from Roof Residual Fallout

As an example, Figure 1 is a fallout deposition curve in grams per ft^2 per time unit as a function of time after detonation.⁷ Because no data on washdown wash-off rates are available, a wash-off rate of 50 percent of the accumulated fallout mass per 0.1 hour was assumed. It was also assumed that 10 percent of the accumulated fallout mass was not removable--i.e., there would be a 10 percent residual.^{8,9} These relationships are expressed as:

$$m = m_1 + m_2 \quad (1)$$

$$\frac{dm_1}{dt} = 0.1 \frac{dm'}{dt} \quad (2)$$

$$\frac{dm_2}{dt} = 0.9 \frac{dm'}{dt} - \frac{0.5}{0.1} m_2 \quad (3)$$

Applying these assumptions to Figure 1, Figure 2 was derived in which comparisons are made of the relative fallout mass accumulation curves for no washdown and washdown. The third step was to apply a radioactive decay function, and the result is Figure 3, which shows the relative dose rates with and without washdown for the fallout period. Integration of the two curves with time gave a dose ratio of approximately 5 to 1 for fallout deposited on the roof only. That is, the dose to a common reference point from roof fallout without washdown was 5 times the dose from roof fallout with washdown.

Transit Dose Rate

The airborne transit dose to an unprotected location has been variously estimated--from negligible to as high as 20 percent of the deposit dose during the deposition period.¹⁰ The portion transmitted through the roof of a structure as opposed to the portion transmitted through the walls is a function of the structure shape and the relative shielding afforded by the roof and walls.

Dose Rate from Adjacent Surfaces

As for the air-scattered radiation, which comes from the contaminated

Figure 1

EXAMPLE FALLOUT DEPOSITION RATE

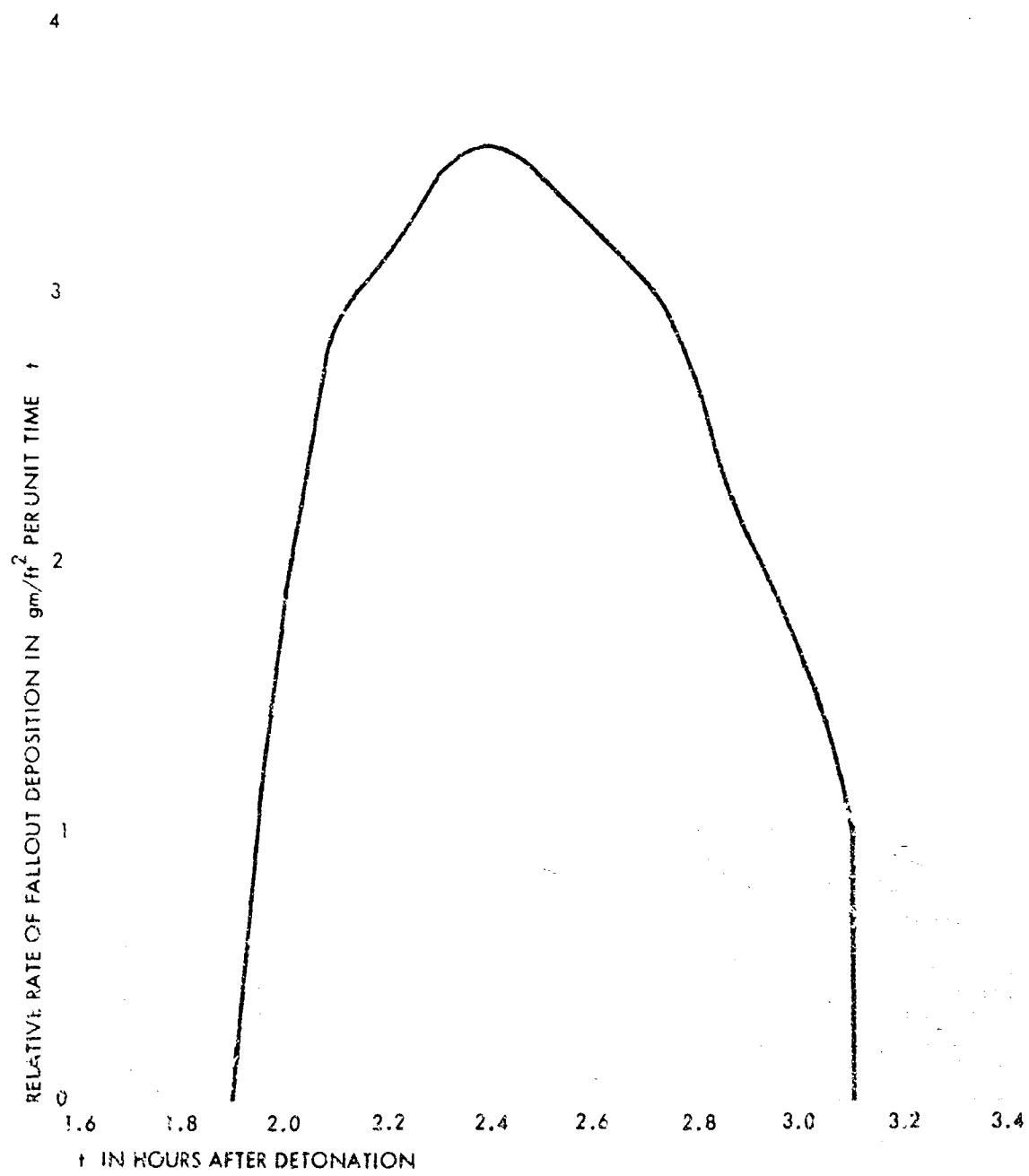


Figure 2
FALLOUT ACCUMULATION

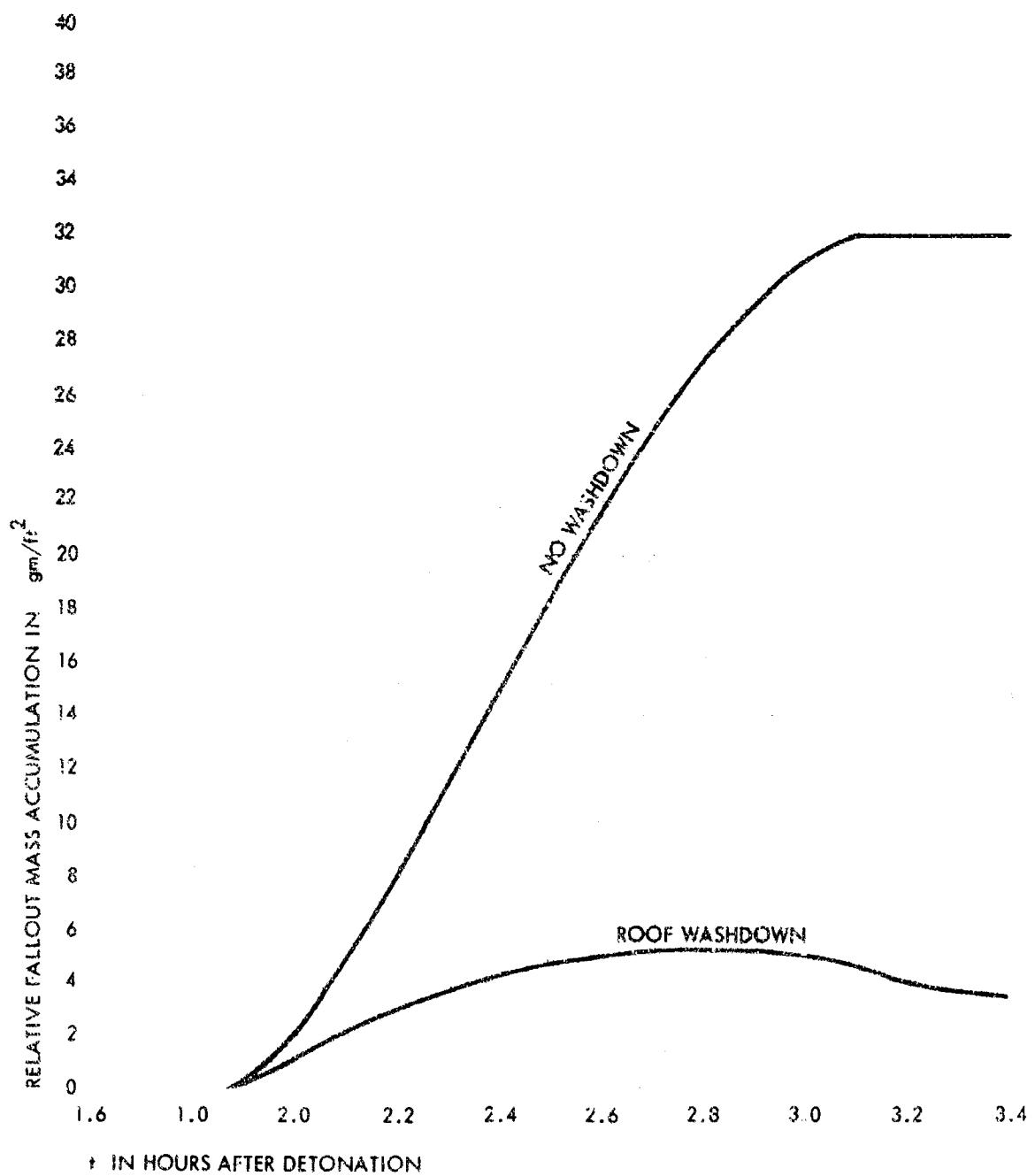
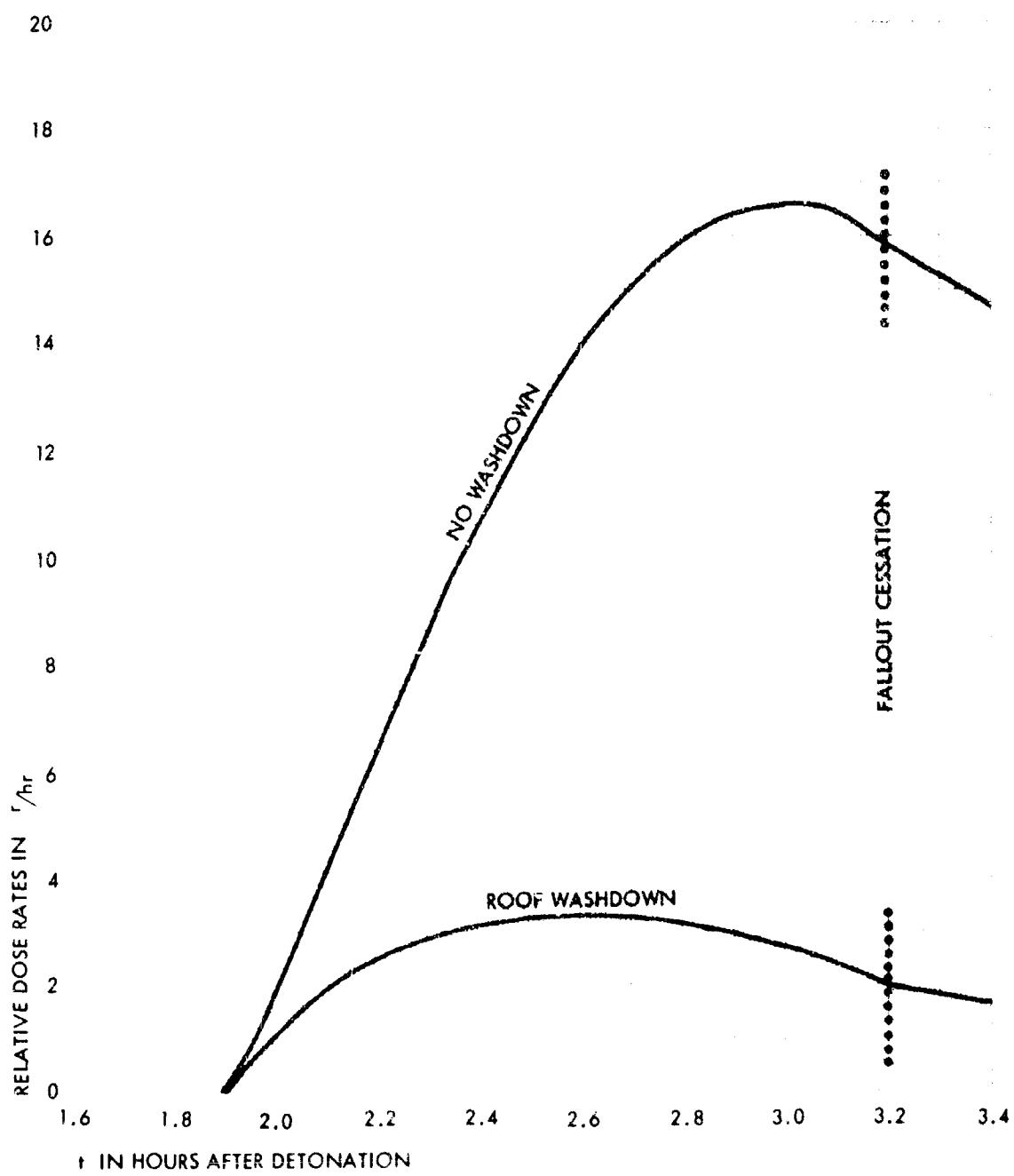


Figure 3

RELATIVE DOSE RATES FROM ACCUMULATED FALLOUT



ground or other roofs, its transmission through the given roof is a function of structural shape, size, and roof shielding.¹¹ The procedure given in Reference 11 was used to estimate the dose rate transmitted into the building from deposited radioactive fallout sources. The ratio of the ground-source radiation that penetrates the roof via air-scattering and the ground-source radiation that penetrates the building wall is the same during and after fallout cessation, neglecting the effects that a changing gamma spectrum might produce.

Accumulated Doses in Terms of Contributing Components

After calculating dose rates, the accumulated exposure dose is determined. In order to estimate exposure doses, certain conditions of the building with respect to occupancy must be known; these include the stay period in the building, the amount of shielding afforded by the building, the height of the roof from the ground, and the size (area) of the roof. For the fallout deposition and residual buildup rates shown in Figure 3, the following conditions were assumed:

Exposure location - 3 ft above floor center

Stay period - 1 week after fallout cessation

Shielding - None (worst case)

Building (roof) height - two values, 10 feet and 20 feet so as to show a range of heights

Roof size - A range from 1,000 sq ft to 100,000 sq ft

Washdown - One situation using washdown, and another not using it

Under these conditions, the dose components to the occupants of a building are calculated as a percent of the total no-washdown dose. Figure 4 is for a roof height of 10 feet, and Figure 5 for a roof height of 20 feet. As can be seen, the roof residual dose with washdown is approximately one-tenth of the roof residual dose without washdown. Also, the exposure dose to occupants from air-scattered radiation through the roof is significant for small structures when compared to the roof residual dose with washdown, and the transit dose is negligible.

The dose received through the walls to a center location in a building from adjacent ground sources is seen to decrease with building area size in Figures 4 and 5. This dose or dose rate component would be further decreased considerably for below grade locations, and for upper

Figure 4

ONE WEEK DOSE COMPONENTS FOR 10FT. TALL
STRUCTURES WITH NO SHIELDING ASSUMED

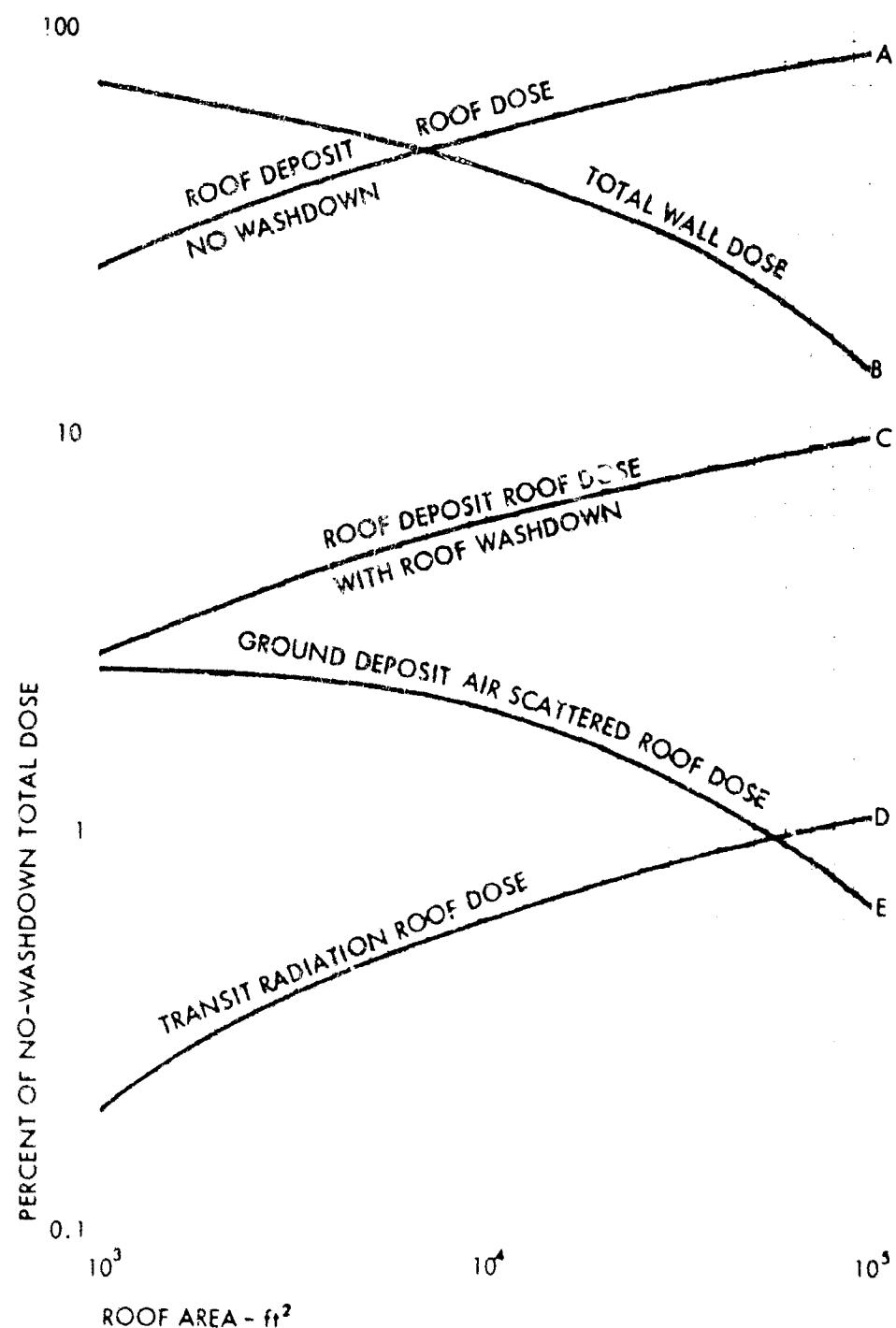
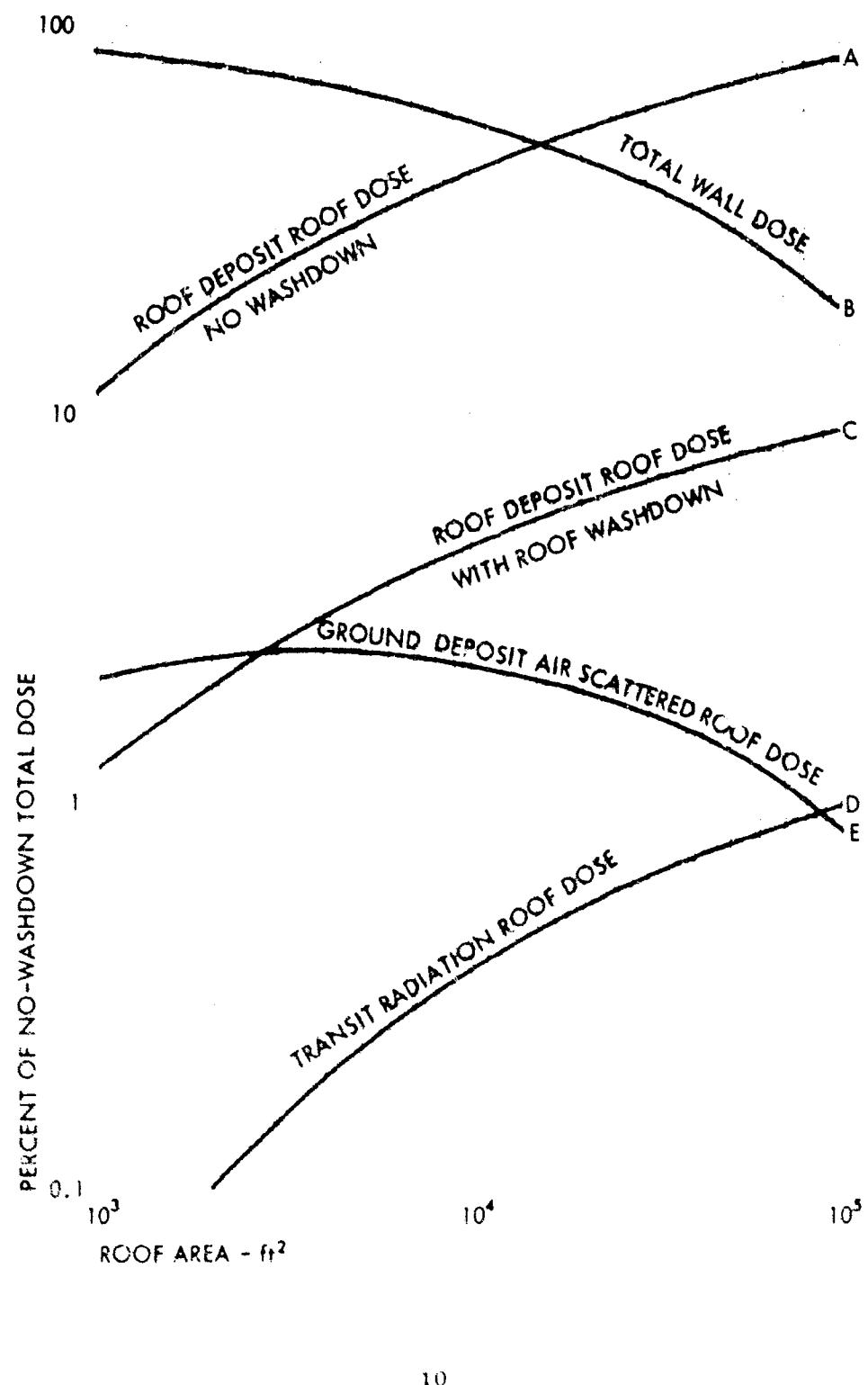


Figure 5

ONE WEEK DOSE COMPONENTS FOR 20FT. TALL
STRUCTURES WITH NO SHIELDING ASSUMED



story locations. As the dose rate component through the building walls decreases, roof protection becomes increasingly important. This can be demonstrated by using a single structural configuration and calculating the roof contribution to the total dose rate within the structure as a function of wall thickness. The very thick walls (heavy mass-thickness) would be representative of a location on the second floor of a two story structure with moderately thick walls, and the thickest walls would be representative of a basement location in a structure with a thin roof and floors. Figure 6 gives the roof contribution to total dose percentage in a 20 foot tall, 1,000 ft² structure, for three roof mass-thicknesses and for various wall mass-thicknesses. As can be seen, the relative roof contribution increases with wall thickness and decreases with roof thickness. The larger the relative roof contribution, the greater the relative effectiveness of the roof washdown system. Thus, if a 10 percent residual washdown system were used upon a structure where the relative roof contribution was 0.90, the dose reduction due to the washdown system would be a factor of 5.3. If, on the other hand, the roof contribution were 0.10, the 10 percent residual washdown system would reduce the exposure dose by only a factor of 1.1.

The equation for the protection factors (PF) of structures without a roof washdown system is

$$PF = 1 / \left(F_{RG} F_{RT} [A + D + E] + F_{WG} F_{WT} B \right) \quad (4)$$

and the equation for the PF of structures with a 10 percent residual roof washdown system is

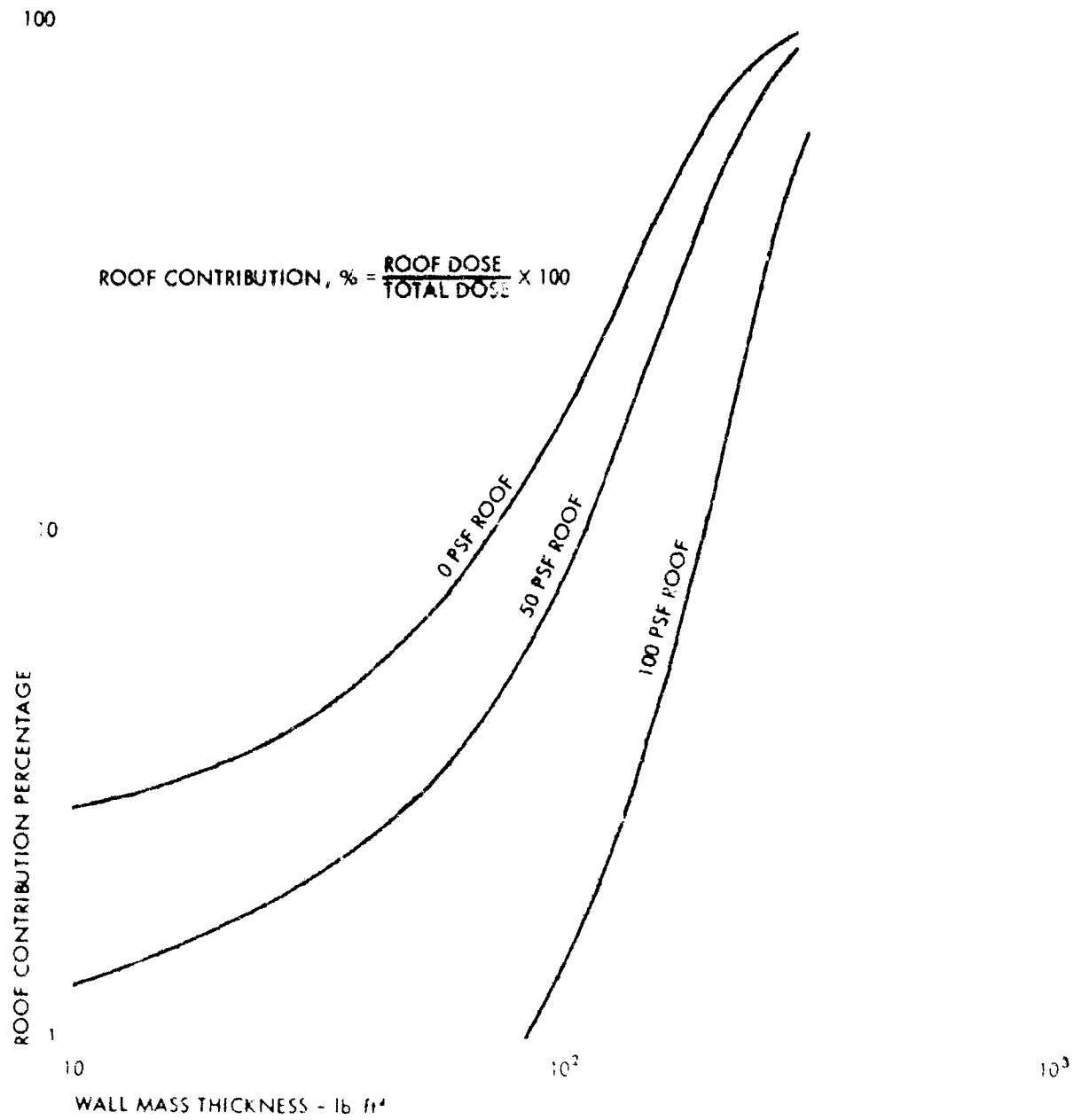
$$PF = 1 / \left(F_{RG} F_{RT} [C + D + E] + F_{WG} F_{WT} B \right) \quad (5)$$

where (see Figures 4 and 5)

- A is the roof residual dose without washdown
- B is the total dose through the walls
- C is the roof residual dose with washdown
- D is the air-scattered roof-dose from ground sources
- E is the transit radiation dose

Figure 6

ROOF CONTRIBUTION PERCENTAGE (20FT. TALL,
1000FT² STRUCTURE)



and where (see Figures 7, 8 and 9)

F_{RG} is the roof geometry reduction factor
 F_{WG} is the wall geometry reduction factor
 F_{RT} is the roof thickness reduction factor
 F_{WT} is the wall thickness reduction factor (To show the variation of F_{WT} with shape, a range of values was included--i.e., 10 and 20 foot walls.)

Figure 10 gives the PFs as a function of roof size for a structure with a 10 foot roof height, with various wall and roof shielding mass thickness combinations, and with or without washdown (calculated by the procedures of Reference 11). Figure 11 shows the calculated PFs as a function of roof size for a structure with a 20 foot roof height and for the same combinations as in Figure 10. As can be seen from the curves in these two figures, no thin roof structure with washdown, having less than 150 PSF wall shielding thickness, qualifies as a shelter (40 PF minimum). Two options for obtaining a protection factor of 40 (or better) are: (1) augment the washdown effectiveness with applied roof shielding; (2) apply sufficient roof shielding to eliminate the need for the washdown system.

Figures 12 and 13 present the equivalent roof mass thickness of the roof washdown system as a function of roof area for roof heights of 10 feet and 20 feet. By rewriting Equation 5 to read

$$F_{RT} = \frac{\frac{1}{PF} - F_{WG} F_{WT} B}{F_{RG} (C + D + E)} \quad (6)$$

the roof thickness reduction factor required with roof washdown for any structural geometry, wall thickness, and desired PF can be determined, and the roof thickness required with the washdown system can be obtained from Figure 8. The required roof thickness to obtain a PF of 40 with and without the roof washdown system for structures with 150 PSF walls is presented as a function of structure size (roof area) in Figure 14. As can be seen, a relatively thin roof with washdown is all that is required for the 20 foot tall structure--i.e., less than 20 PSF--regardless of structure size. This requirement may be compared to roof thicknesses of 70 to 90 PSF that are required without washdown. In the case of the 10 foot tall structures, a relatively thick roof in addition to roof washdown is required for the smaller structures, although a relatively thin roof is adequate for the larger structures. On the other hand, if the wall thickness of the 10 foot tall structures were increased

Figure 7

STRUCTURE GEOMETRY - DOSE REDUCTION FACTORS

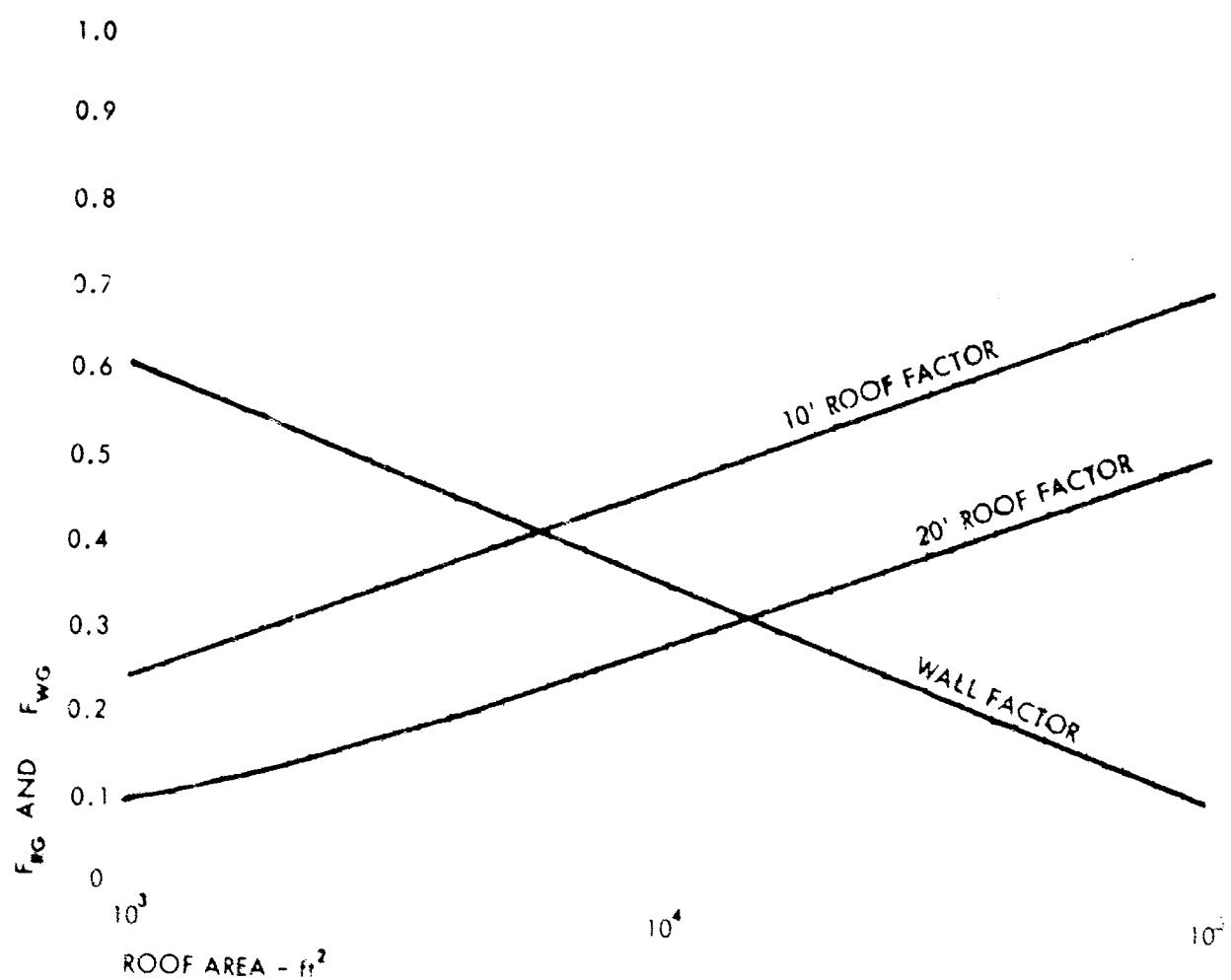


Figure 8
ROOF ATTENUATION FACTORS

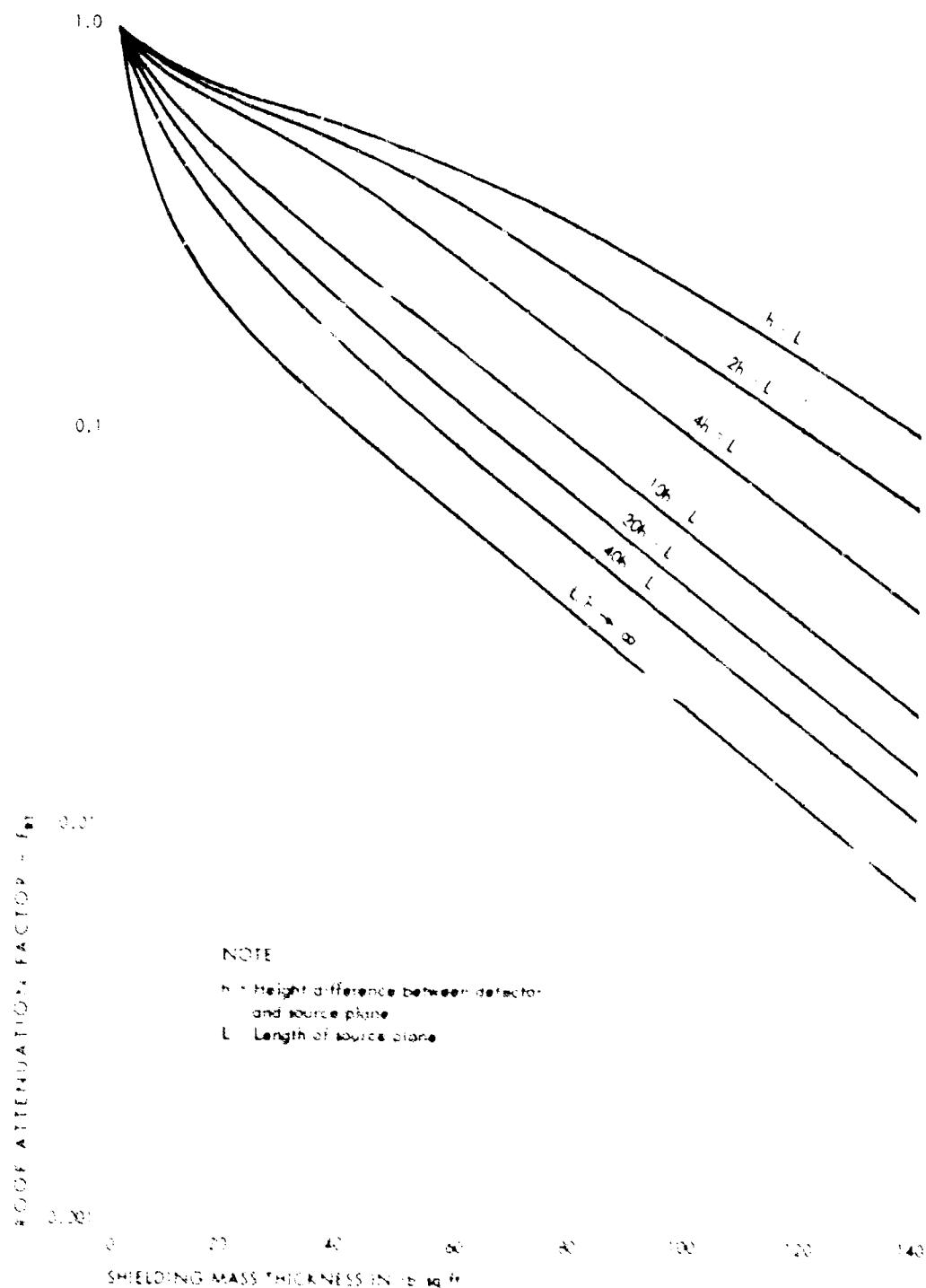


Figure 9
WALL ATTENUATION FACTORS

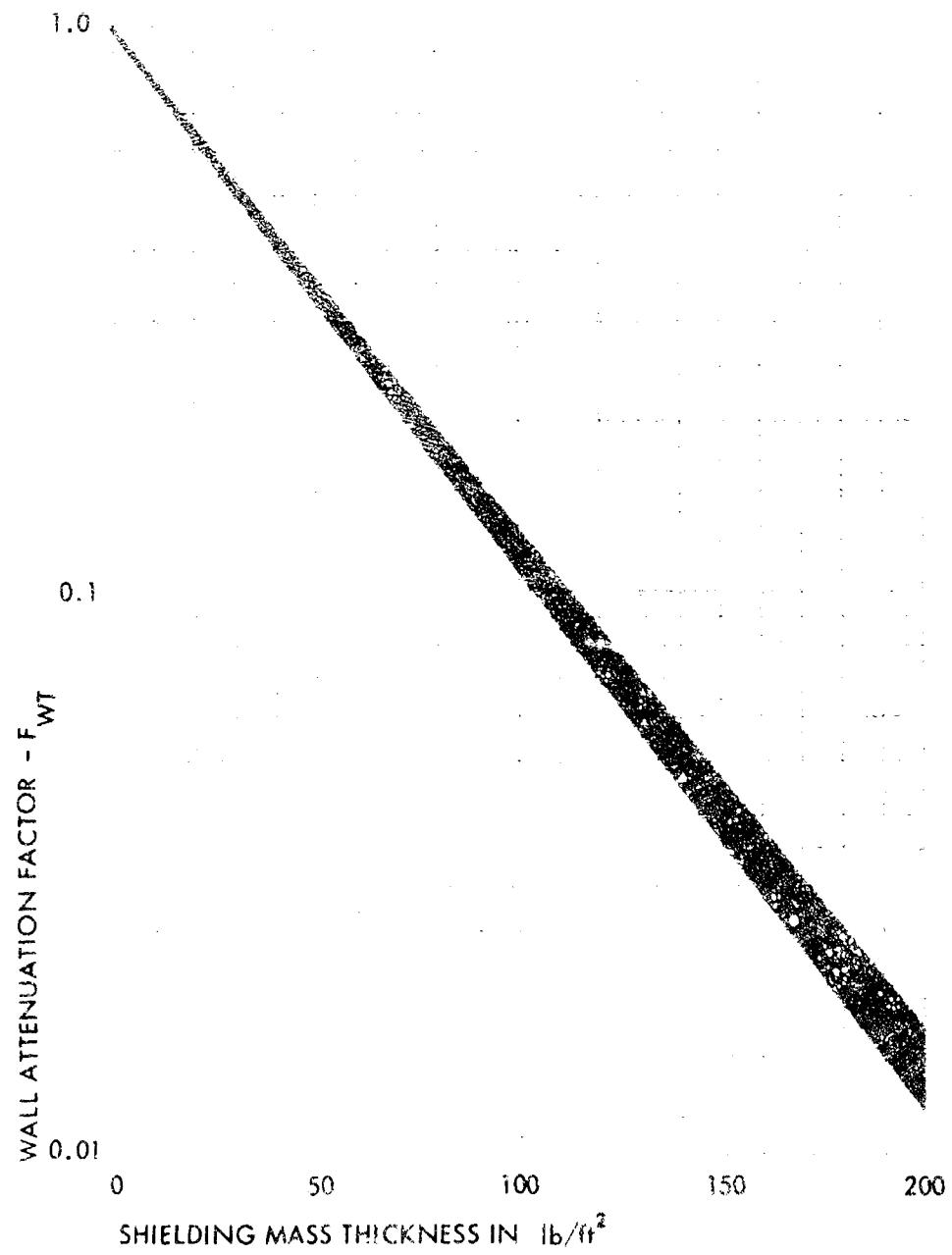


Figure 10

CALCULATED PROTECTION FACTORS FOR 10FT. TALL
STRUCTURES

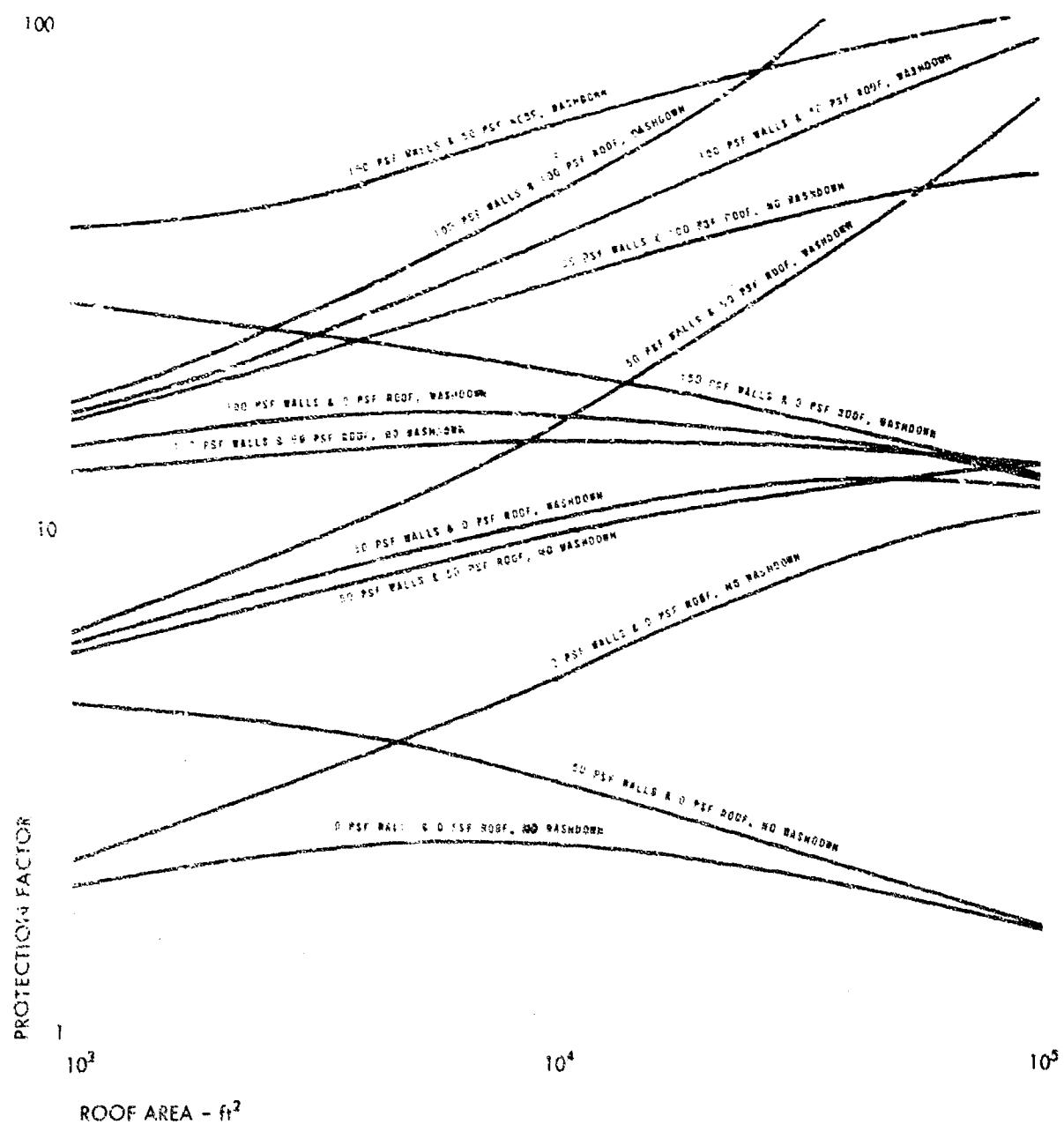


Figure 11

CALCULATED PROTECTION FACTORS FOR 20FT. TALL
STRUCTURES

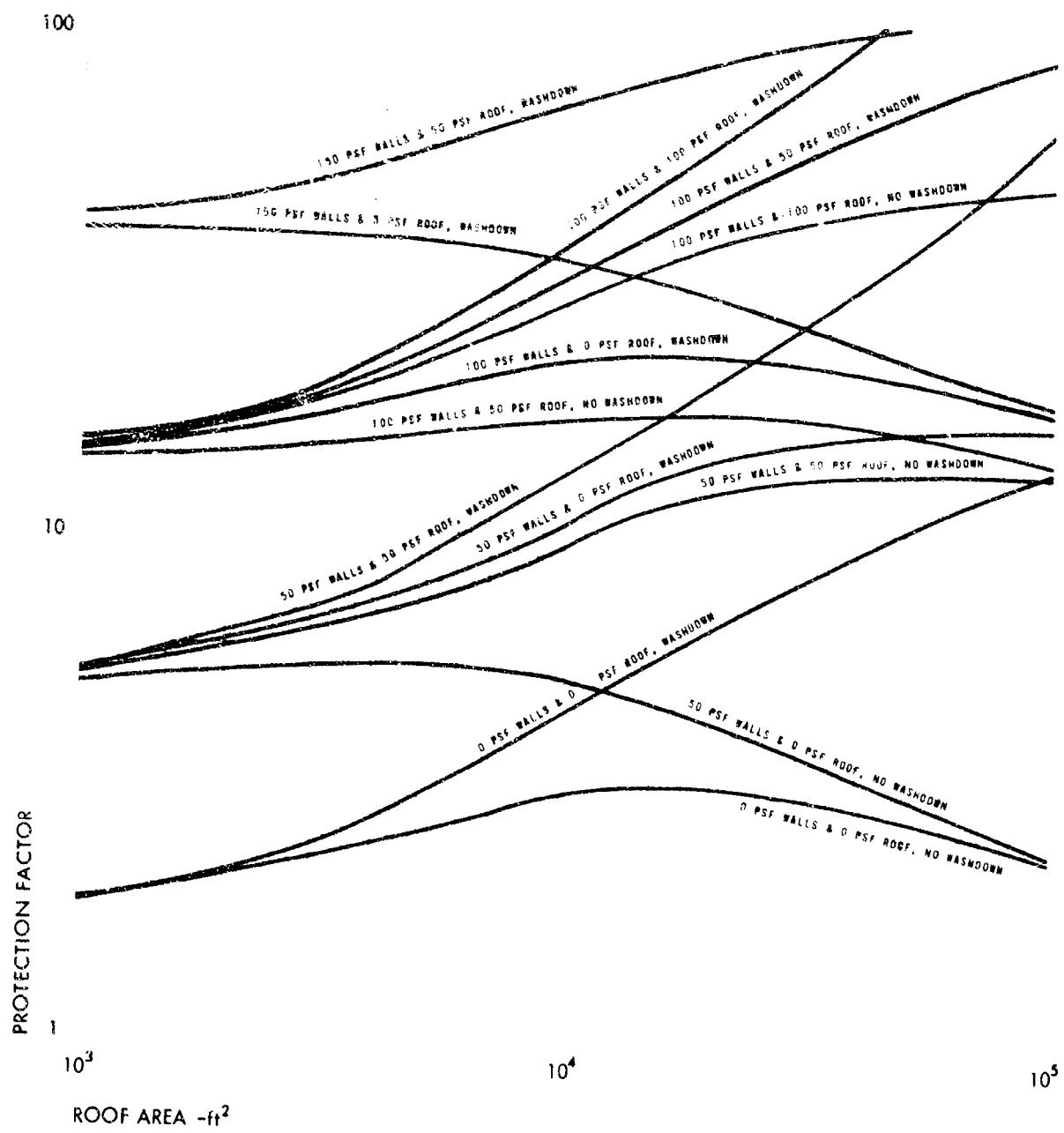


Figure 12

EQUIVALENT ROOF THICKNESS OF WASHDOWN SYSTEM - 10FT. HIGH ROOF

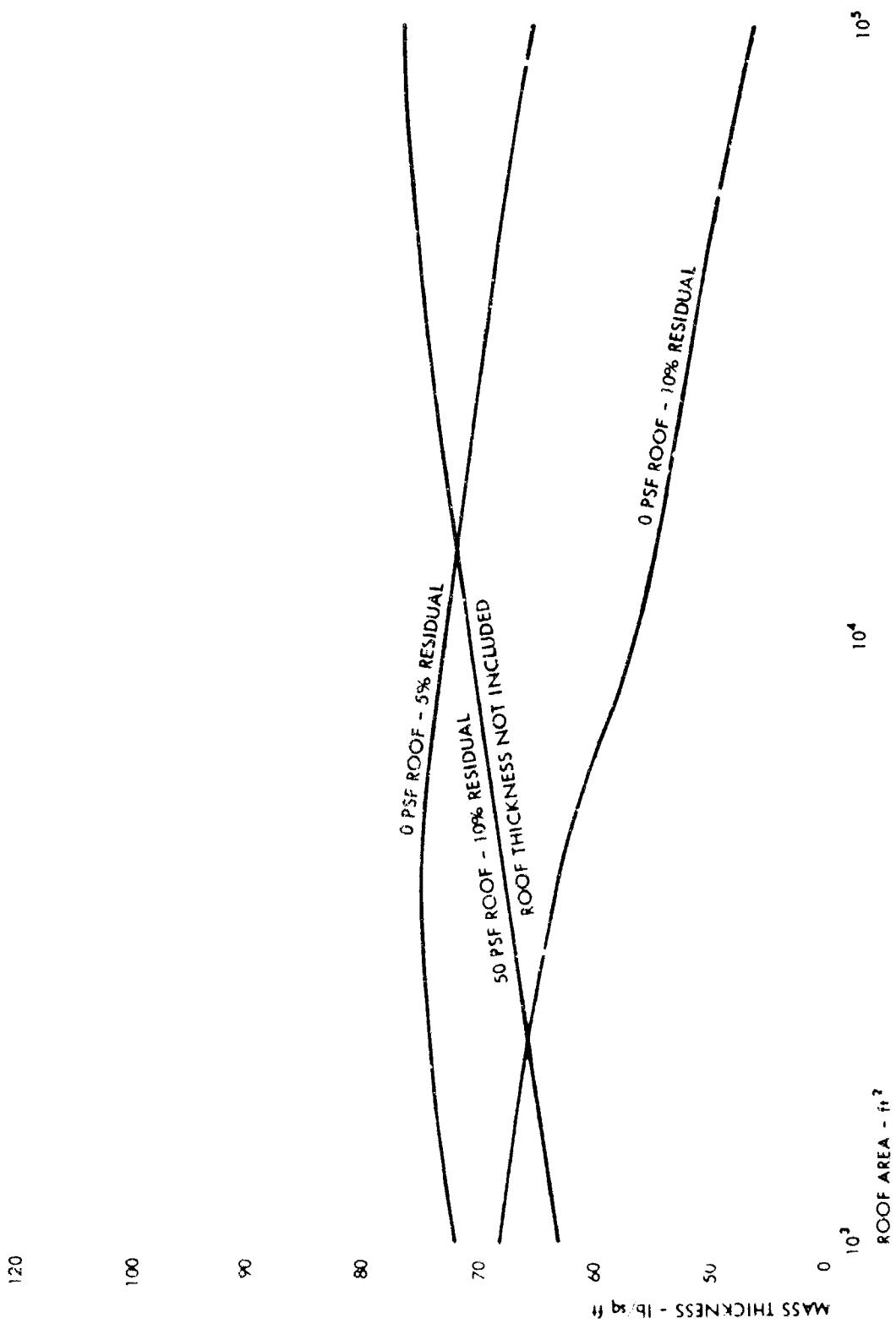


Figure 13
EQUIVALENT ROOF THICKNESS OF WASHDOWN
SYSTEM - 20FT. HIGH ROOF

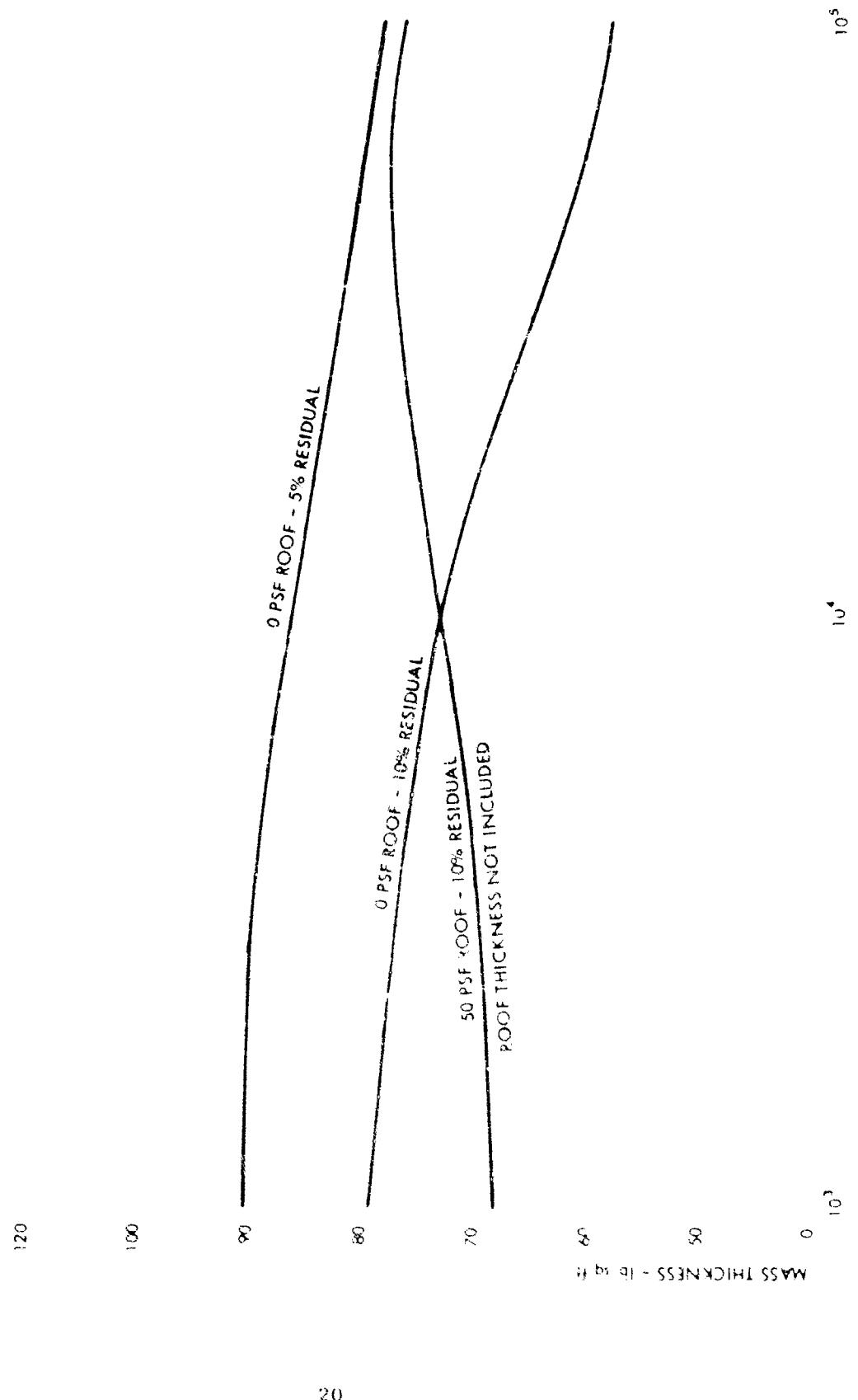
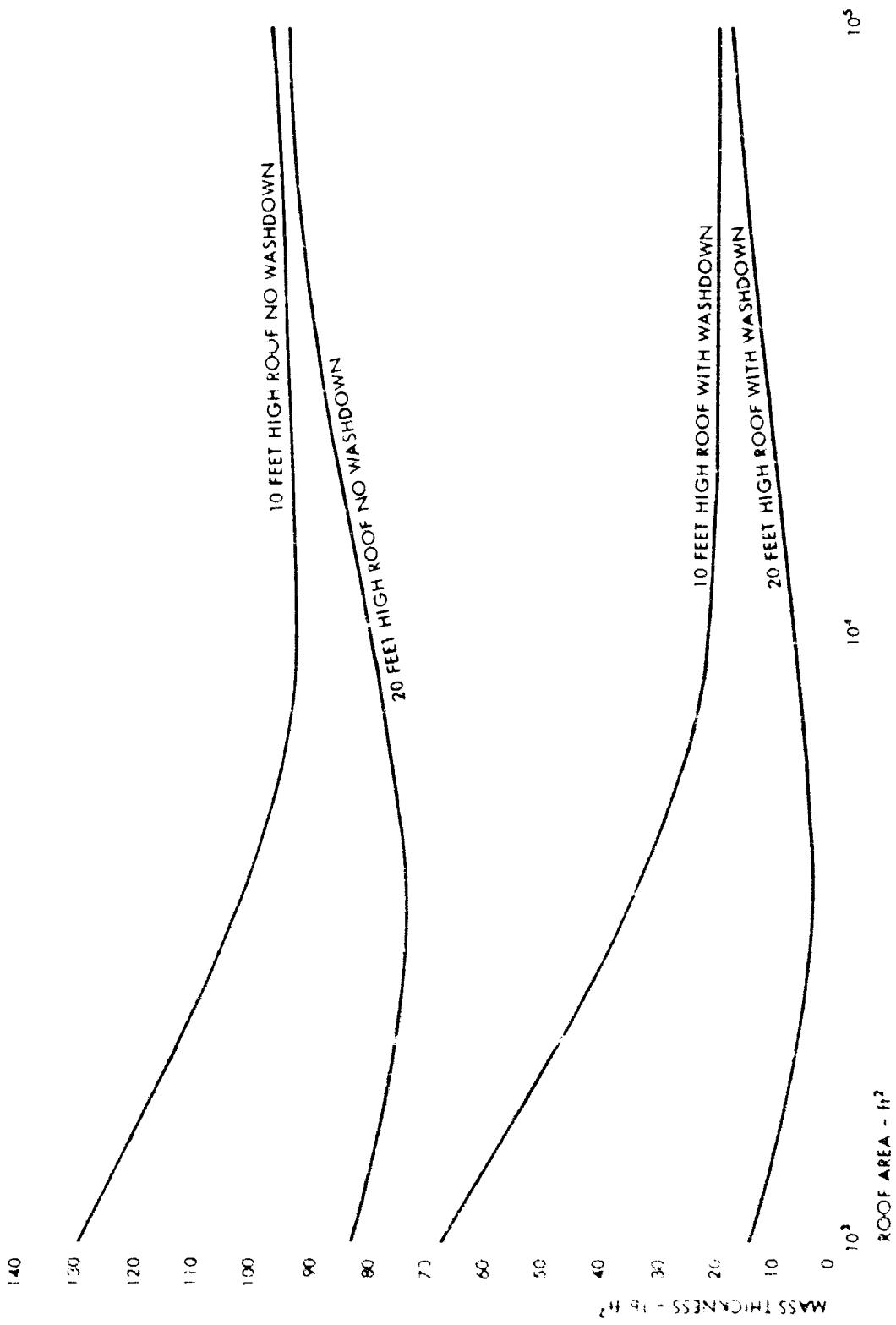


Figure 14
REQUIRED ROOF THICKNESS TO OBTAIN A PF OF 40
FOR STRUCTURES WITH 150 PSF WALLS



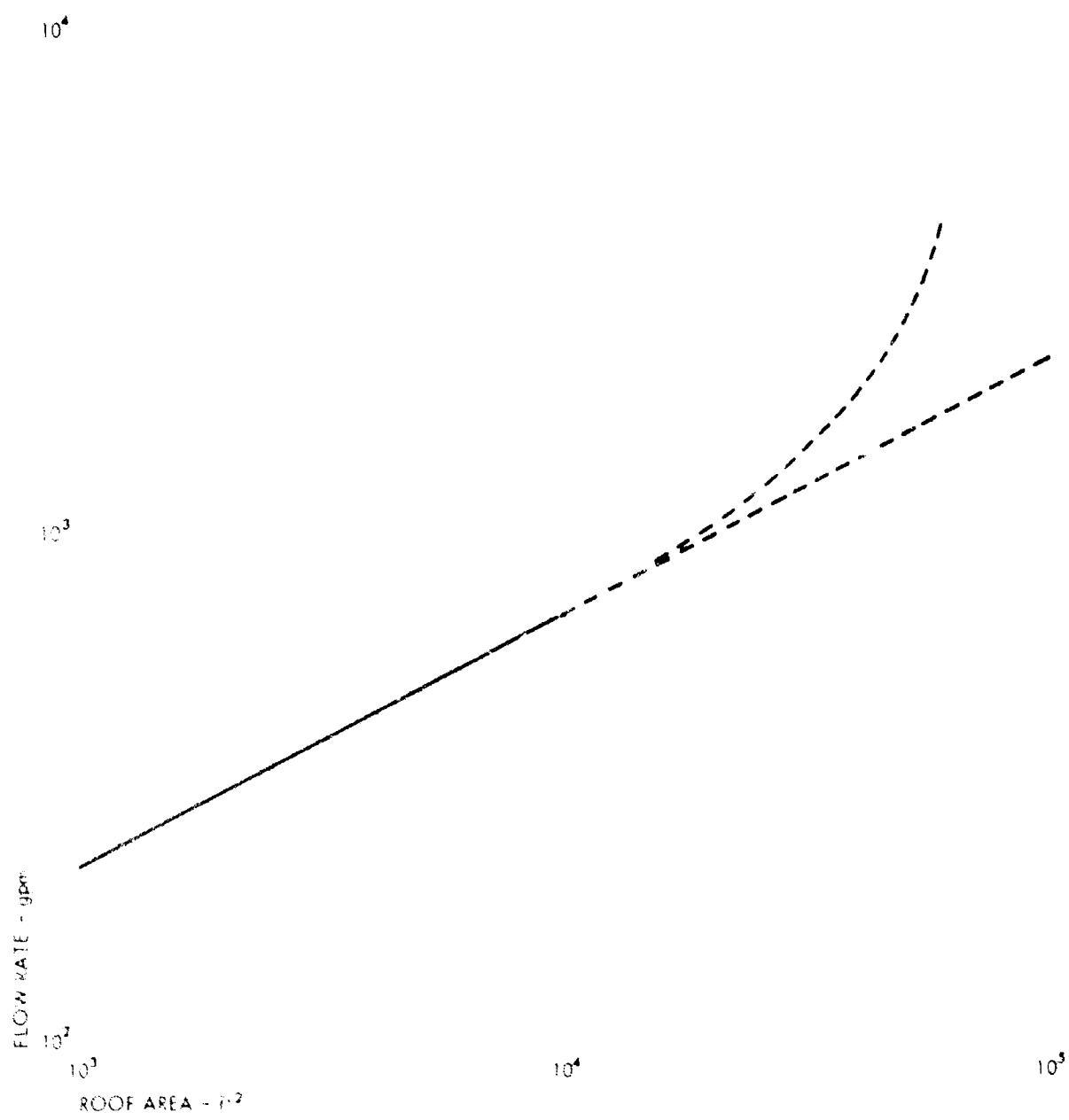
to 175 PSF, then thin roofs (less than 20 PSF) with washdown would also be all that would be required for the smaller structures.

All the above calculations are for a location at the center of the structure and for uniform wall thicknesses and uniform roof thicknesses. At locations away from the center of the structure, the roof-dose/wall-dose ratio will change. This variation will not affect the equivalent roof-washdown, roof-mass-thickness values in Figure 12, and unless extreme locations (e.g., corner locations) are used, the PF values in Figures 10 and 11 and the required roof thickness values in Figure 14 will not be significantly affected.

For very large roofs, the effectiveness of roof washdown systems will be degraded because of the greater amount of fallout that must be carried by the water stream. It is not known what additional amount of water, if any, would be required to overcome any buildup effect that might occur with heavy rates of fallout upon large roofs. Figure 15 shows a suggested washdown flow rate for relatively smooth roof surfaces.⁴⁸ Washdown effectiveness data for various flow rates over longer distance (>50 feet) are nonexistent, and consequently the flow rate requirements for roof areas in excess of 10,000 ft² are represented as dashed lines in Figure 15. Finally, the roof washdown system could be reduced to partial or total ineffectiveness by malfunctions or from freezing at extremely cold temperatures.

Figure 15

WASHDOWN WATER FLOW RATES



COMPARATIVE COSTS

The relative cost of converting conventional structures into shelters either by increasing the roof mass-thickness or incorporating a roof washdown system (along with increasing the wall thickness) depends upon how the original building was constructed. The cost also depends upon the choice of roof washdown system and the choice of shielding materials. Some structures are not suitable to conversion to shelters by the mere application of additional shielding materials on the roofs, and washdown systems are not suitably effective for the roofs of some structures. For such structures the relative costs are indeterminant.

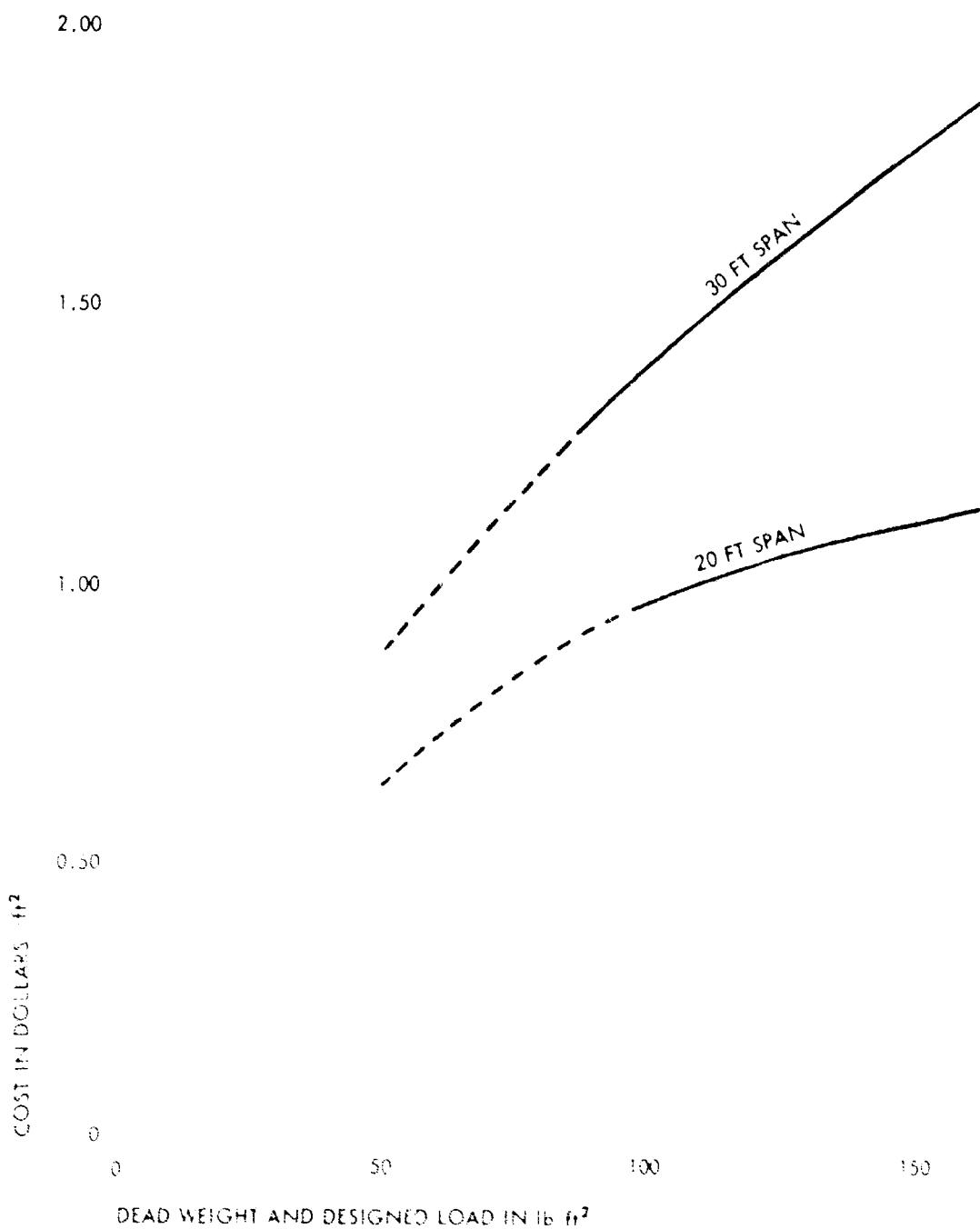
In general, sloped or pitched roofs are suitable for roof washdown; and flat roofs, if they are adequately strong or are amenable to reinforcing, are suitable for applied shielding. On occasion, there are structures with roofs that are suitable for roof washdown as well as for applied shielding. The relative cost of applying shielding or installing a roof washdown system may be compared for these structures. Usually, these structures are of medium to heavy steel construction (the roof support includes girders and open truss joists), have concrete for roofing material (2 to 4 inches thick), and have a slightly sloped roof (e.g., 1:24). The weight of these roofs ranges from about 40 pounds per square foot to about 60 pounds per square foot, and is designed to support live weights of 60 to 100 pounds per square foot.

If additional structural strength is required to support the added roof shielding weight, the cost of providing roof shielding is increased. The construction cost of additional roof support for a 20 foot span and for a 30 foot span on an open structural frame is given in Figure 16.^{14, 15} If the structure to be modified is finished with exterior and interior walls, and with roof and ceiling, and the interior is compartmented, the cost of applying additional structural strength without degrading usefulness and aesthetics is very high, and the overall cost could run as high as, or higher than, the cost of new construction. On the other hand, for structures that do not require additional structural strength, the cost of applying roof shielding over the existing roof is merely the cost of the shielding material and the cost of labor. The cost of six inches of reinforced concrete in place is approximately \$1.00 to \$1.25 per square foot.¹⁴

The cost of installing a roof washdown system on a structure will depend upon the roof type and the type of washdown system. A smooth well-sloped roof requires less water and fewer nozzles than a roof that is

Figure 16

ADDITIONAL COST OF OPEN TRUSS ROOF SUPPORT



rough or has only a slight slope. Three types of washdown systems are described as follows:

1. "Once through," using the normal water supply.
2. "Once through," using stored water or well water, or drawing from a natural body of water.
3. Recirculating, using treated water.

The first type is the least expensive and the least reliable being entirely dependent upon an unimpaired water system. The basic components are piping and nozzles (it may be assumed that, for large structures, adequate drainage exists). The cost of such a system depending upon the shape, texture, and slope of the roof, will range between \$0.10 to \$0.40 per square foot.

The second type is practical only if a high capacity well source or a body of surface water is located nearby. The construction of a storage tank with sufficient capacity for a once through system is exorbitant. If it is necessary to dig a well and install a pump (internal combustion), or if it is necessary to install a pump and a long water line to the nearest body of water then the third type of washdown system will be more economical as well as more reliable.

The third type of washdown system consists of (1) a water and fallout collection system, and (2) a water storage and filtration system as well as the piping and nozzles. In some structures adequate collecting systems exist, and only modifications are needed to channel the return water and fallout to a combination filter and storage tank. In other structures with roof drainage to the eaves, collecting gutters must be installed. Standard rain gutters are inadequate--special larger gutters with a bottom slope of at least 1:16 are recommended,⁴ although there have been no tests of this part of washdown systems. These special gutters will be more costly and will be less aesthetically appealing than standard roof gutters.

Extra piping or conduits will be required to carry the collected water and fallout to a settling chamber, which should be installed below ground so that the collected fallout will be shielded.

A settling tank and a coarse filter are all that is necessary to remove the fallout particles from the return water. The water storage requirements are estimated at 0.2 to 0.5 gallons per square foot of roof, and this ratio includes the volume of the settling compartment. The pumping rate is estimated at 0.02 to 0.05 gallons per minute per square foot of roof area (see Reference 8 for storage tank design).

The water requirements for adequate roof coverage depend upon the roof texture, roof slope, and roof shape. Table 1 gives the cost for the components of the recirculating washdown system (with the installation costs included) and the factors affecting the cost, per square foot of roof. If a component exists as a part of the structure design or as a normal facility component, or if the component is not needed for the type of washdown system desired, the cost of the component may be subtracted from the total cost. The costs are based upon a 10,000 sq ft roof size. The unit cost will be higher for smaller roofs and slightly lower for larger roofs.

Table 1
COST OF AN INSTALLED RECIRCULATING WASHDOWN SYSTEM
FOR A 10,000 SQUARE FOOT ROOF

Component	Factor Affecting Cost	Cost sq ft
Roof Piping and nozzles	Roof texture, roof slope, roof shape*	0.10 to 0.40
Water return system	Roof texture, roof slope, material used	0.07 to 0.12
Storage tank	Roof texture, roof slope, roof shape, soil type	0.09 to 0.18
Pump	Roof texture, roof slope, roof shape, roof height	<u>0.07 to 0.10</u>
Total		0.33 to 0.80

* These three factors determine the pumping rate, footage of piping, number of nozzles, the return system capacity, and the storage tank size.

OTHER CONSIDERATIONS

The removal of fallout from roofs by the washdown system is a preventive measure against the contamination of other target areas by originally deposited roof fallout that would otherwise be subsequently redistributed by the wind. Washdown may also eliminate the necessity for roof decontamination after shelter emergence. On the other hand, the roof washdown system does not add to the structural strength of the building and therefore it is a countermeasure only against fallout radiation.

To add shielding materials to a roof without adding structural improvement does not increase structural strength, and in fact, will decrease structure strength. However, such an addition of shielding materials is "dirt cheap", and some shielding materials such as reinforced concrete, when added to the roof along with structural improvements, would increase structural strength. Thus, a building with a reinforced concrete roof plus structural improvements will be equipped not only with a countermeasure against fallout radiation, but also an increased degree of protection against blast (and perhaps fire) effects.

The comparison of roof shielding with roof washdown effectiveness assumed 100 percent roof retention of fallout for the no-washdown condition. Under some wind conditions, a very high percentage of the fallout on smooth slope roofs would be blown off the roofs.¹² Fallout on these roofs would also be washed away by rain. The wind erosion of fallout even from rather rough flat roofs could be considerable--50 percent dose rate reductions from flat tar and gravel roofs within the first 48 hours by moderate to high winds were recorded in radiological recovery studies conducted by the U.S. Naval Radiological Defense Laboratory at Camp Parks.¹³

The calculations comparing roof shielding with roof washdown effectiveness so did not include the effects of fallout solubility and roof surface adsorptivity. If the degree of fallout solubility and roof surface adsorptivity is significant, the effectiveness of the roof washdown system would be adversely affected. The effects of fallout solubility and roof surface adsorption would be worse with the recirculating roof washdown system.

Finally, a structure that is protected by applied shielding can be relied upon to provide the designed protection when it is needed. With a roof washdown system, on the other hand, malfunctions could occur that could make the system inoperative. The pump engines may not start when called upon, the nozzles may be plugged, the water and fallout conveyance system may be overloaded, and the filter system may be clogged. Although a routine maintenance and testing schedule would increase the reliability of the system, absolute reliability at all times cannot be guaranteed.

CONCLUSIONS

1. The effectiveness of a roof washdown system is limited because currently available roof washdown systems do not remove all the depositing fallout particles, and consequently some additional roof shielding will often be required to provide an acceptable degree of overhead radiation protection.
2. A roof washdown system cannot be directly compared with applied shielding because of the following reasons:
 - a. Applied shielding would be 100 percent reliable and roof washdown may not be as reliable.
 - b. Wind or rain can be expected to remove some of the fallout from smooth sloped roofs. Such weather effects would probably not reduce the radiation from roof sources not removed by roof washdown but they would decrease the radiation from shielded roofs without an operating washdown system.
 - c. Many structures are not suitable for the addition of applied shielding and a washdown system.
3. A roof washdown system is a useful means for increasing the protection of building interiors from fallout radiation under the following conditions:
 - a. Temperature is higher than the temperature at which the water solidifies in the pipes or nozzles, or at which the spray forms snow or sheets of ice on the roof.
 - b. The roof is sloped and has a relatively smooth surface.
 - c. The system has been designed and constructed to operate independently of outside power sources and water supplies to assure reliability.
 - d. The structure equipped with washdown is not damaged by blast (an operating roof washdown system could, however, decrease fire hazards in peripheral blast areas).
4. In general, the cost of a washdown system for large roof area structures with smooth sloped roofs will be less than the cost of providing an equivalent amount of shielding.

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15. ABSTRACT
This study provides guidance on the basic applicability and relative worth of roof washdown as a fallout radiation countermeasure. The basic purpose of roof washdown is to reduce the radiation dose to occupants of a building by preventing or reducing the accumulation of fallout on the roof. However, the roof washdown system does not affect the penetration of the roof by radiation from other sources.
It was found that under some circumstances a roof washdown system is a useful means for increasing the protection of building interiors and that, in general, the cost of a washdown system for large roof area structures with smooth sloped roofs will be less than the cost of providing an equivalent amount of shielding. However, applied shielding provides 100 percent reliability whereas roof washdown systems may not be as reliable.

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